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RESEARCH MEMORANDUM

THE EFFECTS OF BOUNDARY-LAYER CONTROL ON THE LONGITUDINAL CHARACTERISTICS OF A SWEPT-BACK WING USING SUCTION THROUGH STREAMWISE SLOTS IN THE OUTBOARD PORTION OF THE WING

By Gerald M. McCormack and William H. Tolhurst, Jr.

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

An investigation has been conducted to determine the effects of a simplified form of boundary-layer control on the low-speed longitudinal characteristics of a swept-back wing. The objective of the boundary-layer control was to improve the longitudinal characteristics of the swept-back wing at lift coefficients below the maximum. Boundary-layer control was effected by the application of suction to several short streamwise slots located over the forward part of the outboard portion of the wing.

The application of boundary-layer control to the swept-back wing (63° sweepback of the leading edge, taper ratio 0.25, aspect ratio 3.5, 12.5-percent chord leading-edge flap deflected 35°) delayed the occurrence of separation from an angle of attack of about 8.5° to an angle of attack of about 14° (the corresponding lift coefficients were 0.41 and 0.68, respectively). As a result, at an angle of attack of 14°, the drag coefficient was reduced about 30 percent and the rearward shift of the aerodynamic center was eliminated. For angles of attack greater than 14°, separation occurred inboard of the slots and nullified the effects of boundary-layer control.

In order to control separation between angles of attack of 8.5° and 14°, three short streamwise slots located over the forward part of the upper surface of the wing at 65.6-, 78.9-, and 91.1-percent semispan were required. The slots were between 5 and 13 percent of the local streamwise chord long and between 1 and 7 percent of the local streamwise chord wide.

INTRODUCTION

A number of investigations have shown that serious deficiencies exist in the low-speed characteristics of highly swept wings. The deficiencies include high values of drag coefficient, large movements of the aerodynamic center, and loss of control effectiveness. For wings with little or no camber, these deficiencies are due to widespread separation of air flow from the leading edge of the wing. The separation occurs at a low lift coefficient relative to the maximum lift coefficient attainable by the wing.

The investigation reported in reference 1 showed that substantial improvements were obtainable in the low-speed characteristics of a swept-forward wing by the application of boundary-layer control to the wing. Suction was applied to a single slot at the wing-fuselage juncture in such a manner as to remove the unstable boundary-layer flow that occurred over the inboard sections. As a result separation over the inboard sections was delayed and, owing to a natural spanwise boundary-layer drain, a postponement of separation over the entire wing was obtained.

In consequence of the results of reference 1, it was reasoned that a system of boundary-layer control of the kind applied to the swept-forward wing should give similar results on a swept-back wing. An investigation was accordingly undertaken in the Ames 40- by 80-foot wind tunnel to investigate this possibility.

The model tested differed considerably from the previously tested 45° swept-forward wing and was subject to certain shortcomings insofar as the application of boundary-layer control was concerned. The sweep was extreme (63° sweepback of the leading edge), the taper ratio was high, and the area available for ducting was relatively small. The model was available, however, and was considered adequate for the investigation.

A previous investigation of this swept-back wing (reference 2) showed that, for lift coefficients greater than about 0.2, the drag began to increase rapidly and the aerodynamic center shifted first rearward (from $0.38\bar{c}$ to $0.52\bar{c}$) and then forward (from $0.52\bar{c}$ to $0.25\bar{c}$ forward of the leading edge). These irregularities were due to separation of the flow from the leading edge. The separation occurred first over the outboard sections of the wing, and progressed inward as the angle of attack was increased. Postponement of the leading-edge separation with consequent improvement in the longitudinal characteristics of the wing at lift coefficients below the maximum was the objective of the boundary-layer control applied in this investigation.

Suction was applied to short streamwise slots in the outboard portion of the wing in order to remove the unstable boundary-layer flow that occurred over the outboard sections and consequently to delay separation over this area. The indications of reference 1 were that a postponement of separation over the entire wing would result since the spanwise boundary-layer drain, which is a natural system of boundary-layer control inherent to swept wings, would stabilize the flow over inboard sections to higher angles of attack. This is an alternative form of boundary-layer control to that reported in reference 3 in which control is applied along the entire span of the leading edge of the wing with no dependence on the natural boundary-layer control inherent to the wing.

The wing was equipped with full-span leading-edge flaps since the investigation reported in reference 1 showed that boundary-layer control was more effective when a leading-edge flap was deflected. Furthermore, deflecting the leading-edge flap moved the position of initial separation from the leading edge, where the negative pressures were very high, to the hinge line of the flap, where the negative pressures were considerably lower. As a consequence, the pressure ratio required of the suction pump was reduced. The influence of the fuselage in the system of boundary-layer control applied to the 45° swept-forward wing (reference 1) was not known. Accordingly, to provide for any such effects that might be beneficial, bodies of revolution were mounted on each wing tip of the swept-back wing to simulate the effects of the fuselage of the swept-forward wing.

NOTATION

The coefficients and symbols used for the presentation of data are defined as follows:

A aspect ratio $\left(\frac{b^2}{S}\right)$

a.c. aerodynamic center location measured as a fraction of the mean aerodynamic chord, positive aft of the leading edge

b wing span, feet

C_D drag coefficient $\left(\frac{\text{drag}}{qS}\right)$

$C_{D_{min}}$ minimum drag coefficient

C_L lift coefficient $\left(\frac{\text{lift}}{qS}\right)$

$C_{L_{C_{D_{min}}}}$ lift coefficient at which minimum drag was obtained

$C_{L_{max}}$ maximum lift coefficient

$C_{L_{sep}}$ lift coefficient at which separation of the boundary layer first occurred to a significant extent

C_m	pitching-moment coefficient computed about the quarter-chord point of the mean aerodynamic chord $\left(\frac{\text{pitching moment}}{qS\bar{c}}\right)$
C_Q	total suction flow coefficient of both wing panels, based on free-stream density and total wing area $\left(\frac{Q}{VS}\right)$
c	local chord measured perpendicular to leading edge, feet
c_x	local chord measured parallel to plane of symmetry, feet
$\bar{c}$	mean aerodynamic chord $\left(\frac{\int_0^{b/2} c_x^2\, dy}{\int_0^{b/2} c_x\, dy}\right)$, feet
c_n	section normal-force coefficient $\left(\frac{1}{c}\int_0^c P\, dx\right)$
e	airplane efficiency factor defining the shape of the drag polar $\left[\frac{1}{\pi A}\ \frac{d\left(C_L - C_{L_{C_{D_{min}}}}\right)^2}{dC_D}\right]$
P	pressure coefficient $\left(\frac{p_l - p}{q}\right)$
p	free-stream static pressure, pounds per square foot
p_l	local static pressure, pounds per square foot
Q	quantity of air drawn through suction slots, cubic feet, per second
q	free-stream dynamic pressure, pounds per square foot
R	free-stream Reynolds number based on mean aerodynamic chord
S	wing area, square feet
V	free-stream velocity, feet per second
x	chordwise coordinate parallel to plane of symmetry, feet

y spanwise coordinate perpendicular to plane of symmetry, feet

α angle of attack of chord plane of basic wing, degrees

MODEL

A photograph of the 63° swept-back wing model mounted in the wind tunnel is shown in figure 1. The geometric characteristics and dimensions of the model are given in figure 2. The wing had 63° sweepback of the leading edge, an aspect ratio of 3.5, a taper ratio of 0.25, an NACA 64A006 airfoil section in a streamwise direction, no twist, no camber, no dihedral, and zero incidence. The wing was mounted on the center line of the fuselage.

The fuselage had a fineness ratio of 10.5 and a circular cross section. The fuselage was formed of a fineness ratio 12 fuselage with the after portion removed in order to provide an exit for the boundary-layer control suction pump contained in the fuselage.

A centrifugal pump was used to provide suction. This pump was the compressor unit of a General Electric I-16 turbojet and was driven by two variable-speed electric motors which developed a total of about 720 horsepower at 12,000 rpm. The major portion of this power was required by the sharp-edge slots and crude ducting arrangements used on this test and is greater than would be required with a refined ducting system.

The slots used for boundary-layer control were cut in the forward part of the upper surface of the outboard portion of the wing except for the most outboard slot which was cut in the wall of the tip tank. Dimensions of the various slot configurations are shown in figure 3. Air drawn through the slots passed through the hollow spar of the wing into the fuselage, which acted as a plenum chamber, and was pumped out the exit at the after end of the fuselage. Total-head tubes were installed in the exit in order to measure the quantity of flow.

The wing was equipped with full-span leading-edge plain flaps (fig.4) hinged about the 0.125c line (of sections perpendicular to the leading edge) on the lower surface of the wing. The transition surface between the upper surface of the flap and the wing was an arc with the center at the hinge line.

Pressure orifices were positioned over the upper and lower surfaces of the left wing panel at three streamwise sections. They were located at 30 percent, 60 percent, and 90 percent of the semispan. The chordwise locations are given in table I.

The wing-tip tanks were bodies of revolution having a fineness ratio of 6. Ordinates for the tanks are given in table II. The tanks were symmetrically mounted on the wing tips as shown in figures 1 and 2.

TESTS

Force data, pressure-distribution measurements, and tuft studies were obtained through an angle-of-attack range at zero sideslip. The data were obtained at airspeeds of 63, 100, and 140 miles per hour corresponding respectively to Reynolds numbers of 5, 8, and 10×10^6. The low-speed tests were made in order to obtain higher flow coefficients for the boundary-layer control investigation; the higher speed tests were made in order to correspond more closely to flight Reynolds number.

The force data have been corrected for air-stream inclination and for tunnel-wall effects. A brief analysis indicated that the tunnel-wall corrections were approximately the same for unswept and swept wings of the relatively small size under consideration. Therefore, the corrections for an unswept wing of the same area and span were applied as follows:

$$\Delta\alpha = 0.48\ C_L$$

$$\Delta C_D = 0.0084\ {C_L}^2$$

No corrections have been applied for the drag and interference of the struts. With the exception of the effect on the drag results, these corrections are believed to be negligible. The correction to drag is of the order of $\Delta C_D = -0.015$ at zero lift, but is not known with sufficient accuracy to warrant application. This must be borne in mind when the drag data are analyzed in terms of flight characteristics. The values of suction flow coefficient were measured at the exit at the after end of the fuselage and include the total flow from all ducts in both wing panels. The effect of jet thrust on the force tests was small and had no significant effects insofar as the results of this test are concerned. Therefore, no corrections for jet thrust have been applied to the force data.

Appreciable differences (though not significant within the purposes of this investigation) were noted between certain data for like configurations obtained at different times during the investigation, and also between certain data obtained during this investigation and data obtained during the investigations of references 2 and 3. These differences were due to slight changes in the model configuration, primarily changes in surface finish, that occurred from time to time as modifications were made to the model.

RESULTS AND DISCUSSION

In the following discussion the data obtained prior to the application of boundary-layer control will be briefly described first. The effects of boundary-layer control will then be evaluated.

Characteristics of Wing Without Boundary-Layer Control

The longitudinal characteristics of the plain wing are shown in figure 5. At lift coefficients greater than about 0.32, the drag began to increase beyond that which would be expected[1] and the pitching-moment curve indicated that the aerodynamic center shifted from $0.39\bar{c}$ to about $0.9\bar{c}$. At lift coefficients greater than about 0.50, the drag began to increase even more rapidly and the aerodynamic center shifted forward to $-0.06\bar{c}$. These changes in the longitudinal characteristics of the wing were due to a separation of flow that occurred first over the outboard sections of the wing and progressed inboard as the angle of attack was increased.

The characteristics of the wing equipped with leading-edge flaps deflected 35° and 45° are shown in figure 6. These data showed that the leading-edge flaps deflected 35° were more effective. Separation was delayed to a lift coefficient of about 0.42 and longitudinal instability (extreme forward shift of the aerodynamic center) did not occur until a lift coefficient of about 0.80 was reached. Consequently, for the investigation of the effects of boundary-layer control, the leading-edge flap was deflected 35°.

A comparison of the data for the various configurations at various Reynolds numbers (figs. 5 and 6) showed that within the range investigated Reynolds number had nc significant effects on the longitudinal characteristics of the wing.

The longitudinal characteristics of the wing with the leading-edge deflected 35° and with tip tanks attached are shown in figure 7.

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[1]The index for the drag polar is taken to be the parabola

$$C_D = C_{D_{min}} + \frac{\left(C_L - C_{L_{C_{D_{min}}}}\right)^2}{\pi A e}$$

where e was determined before separation occurred, in the usual manner. This equation is not strictly applicable to highly swept wings but is useful for the purposes of this investigation.

A summary of the characteristics of the wing with the various configurations at a Reynolds number of 5×10^6 follows:

Configuration (a)	$C_{L_{sep}}$ (b)	C_L at which a.c. moved forward	Estimated $C_{L_{max}}$ (c)	Figure
A	0.32	approx. 0.50	1.25	5
B	.42	approx. .80	1.25	6(a)
C	.46	approx. .65	1.25	6(a)
D	.41	approx. .80	1.35	7

[a]Configuration A, plain wing; B, wing with leading-edge flap deflected 35°; C, wing with leading-edge flap deflected 45°; and D, wing with leading-edge flap deflected 35°, tip tanks attached.

[b]The value of the lift coefficient at which separation first occurred to a significant extent $C_{L_{sep}}$ was determined mainly from graphs of C_D vs C_L^2 which reveal the effects of separation very clearly.

[c]Actual $C_{L_{max}}$ could not be obtained due to mechanical limitations of the model-support system. The values given were estimated by extrapolation of the data.

Effects of Boundary-Layer Control

Suction was applied through short streamwisc slots located in the outboard portion of the wing. Spanwise, the slots were located between 0.563 b/2 and 0.911 b/2. Chordwise, the slots were located between 0.119c and 0.247c (see fig. 3) in order to apply suction to the region on the upper surface over the hinge line of the leading-edge flaps. (The tests of reference 1 indicated that this was by far the most effective region in the case of the 45° swept-forward wing.)

Initially, suction was applied through a single slot at the wing tip. It was found, however, that while exerting a small amount of control, a single slot would not give the degree of control desired. Additional slots were therefore cut, one at a time, into the wing inboard of the tip slot (fig. 3). Each slot was ducted separately to the fuselage in order to obtain approximately the same amount of flow through each slot. The results of these tests are shown in figure 8 and are summarized as follows:

Configuration (a)	$C_{L_{sep}}$	$\Delta C_{L_{sep}}$	C_Q	Slot location, 2y/b
Slots closed	0.41	– –	– –	
1 slot	.57	0.16	0.0070	0.911
2 slots	.64	.23	.0076	0.911, 0.789
3 slots	.68	.27	.0082	0.911, 0.789, 0.656
4 slots	.68	.27	.0089	0.911, 0.789, 0.656, 0.563

[a]Leading-edge flap deflected 35° with all slot configurations.

It is evident that boundary-layer control in this form effected a significant delay in the occurrence of separation. The extent to which separation was delayed increased as the number of slots installed in the wing was increased until a total of three slots were in operation. An additional slot (four slots in operation) did not give any further delay but required a higher quantity of flow. Thus, three slots located over approximately the outboard 35 percent of the wing span gave the best results, delaying the appearance of the detrimental effects of separation from an angle of attack of about 8.5° ($C_L = 0.41$) to an angle of attack of about 14° ($C_L = 0.68$).

In order to facilitate comparisons of the data, the principal results of the tests have been replotted in figure 9. The application of boundary-layer control reduced the drag at lift coefficients greater than about 0.30, the maximum reduction being about 30 percent[2] at a lift coefficient of 0.68. Also the rearward shift of the aerodynamic center was eliminated. Corresponding improvements should be obtained in aileron or elevon control effectiveness owing to the elimination of separation over the outboard portion of the wing.

The section pressure distributions show in more detail the effects of the boundary-layer control on the flow conditions over the wing. The pressure distributions over three spanwise stations with and without suction are shown in figure 10. The corresponding section normal-force curves, which were obtained by integrating the pressure distributions, are shown in figure 11. Without suction, at angles of attack of 7.2° and greater the pressures measured at 0.90 b/2 did not recover normally

[2]This value was based on drag coefficients that were determined by subtracting from the values shown in figure 9 a strut drag estimated to be equivalent to a wing drag coefficient of 0.015. (See section entitled "Tests".)

to the trailing edge, and the negative pressure peak over the upper surface opposite the hinge line of the leading-edge flap decreased with further increase of angle of attack (cf., figs. 10(a) and 10(b)). This indicated that separation was occurring in the outboard area. With suction applied, complete pressure recovery was obtained up to an angle of attack of 10.3°(fig. 10(d)). Above 10.3° (cf., figs. 10(d) and 10(e)) the suction peak over the upper surface opposite the hinge line failed to increase further, indicating that local separation was taking place. The section characteristics did not deteriorate, however, until angles of attack greater than about 14° were reached (fig. 11). At angles of attack greater than 14° (fig. 10(g)) the suction peak at the leading edge began to decrease and the section began to lose lift. Thus, it is evident that suction applied through several short streamwise slots in the outboard 35 percent of the wing span postponed the occurrence of the detrimental effects of separation over the 63° swept-back wing to angles of attack greater than about 14° (separation occurred without suction at angles of attack greater than about 8.5°).

At angles of attack greater than 14°, however, it was not possible to control separation. Installing an additional slot farther inboard gave no beneficial effect (cf., the results obtained with slots at 0.656, 0.789, and 0.911 b/2 with the results obtained with slots at 0.563, 0.656, 0.789, and 0.911 b/2). Other tests were also made: Additional slots were installed so as to decrease the spacing between the slots; the slot sizes and shapes and the chordwise locations of the slots on the wing were varied. These changes had no significant effect on the occurrence or sequence of separation. It is possible that, if a number of additional slots had been installed in the wing over the inboard sections, control of separation might have been extended to higher angles of attack. The form of boundary-layer control as applied in this investigation, however, was visualized as a relatively simple application. Additional slots would necessitate a more complex system in which case a system of boundary-layer control such as reported in reference 3 would likely be more suitable.

The ineffectiveness of this form of boundary-layer control at angles of attack greater than 14° was due to the inability of the suction to prevent separation from occurring inboard of the slots. The pressure distributions showed effects of separation at 0.30 semispan at an angle of attack of 14.4°. This effect can be seen by comparing figures 10(e) and 10(f); the pressures did not recover in a normal fashion, as indicated by the bulge in the pressure distribution aft of the hinge line, disclosing a region of separated flow. Tuft studies also indicated separation over this region and, furthermore showed that the separation extended entirely to the wing-fuselage junction. Thus, when separation occurred inboard of the slots, the suction was no longer able to prevent the occurrence of detrimental effects of separation.

CONCLUDING REMARKS

A wind-tunnel investigation has been conducted to determine the effects of applying a simplified form of boundary-layer control to a highly swept-back wing. The boundary-layer control was in the form of suction applied to several short streamwise slots located over the forward part of the outboard portion of the wing.

The application of boundary-layer control to the swept-back wing (63° sweepback of the leading edge, taper ratio 0.25, aspect ratio 3.5) delayed the occurrence of separation from an angle of attack of about 8.5° to an angle of attack of about 14°. (The corresponding lift coefficients were 0.41 and 0.68, respectively.) As a result, at an angle of attack of 14°, the drag coefficient was reduced about 30 percent and the rearward shift of the aerodynamic center was eliminated. For angles of attack greater than 14°, separation occurred inboard of the slots and nullified the effects of the boundary-layer control.

In order to control separation between angles of attack at 8.5° and 14°, three short streamwise slots located over the forward part of the upper surface of the wing at 65.6-, 78.9-, and 91.1-percent semispan were required. The slots were between 5 and 13 percent of the local streamwise chord long and between 1 and 7 percent of the local streamwise chord wide.

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REFERENCES

1. McCormack, Gerald M., and Cook, Woodrow L.: Effects of Boundary-Layer Control on the Longitudinal Characteristics of a 45° Swept-Forward Wing-Fuselage Combination. NACA RM A9K02a, 1950.

2. McCormack, Gerald M., and Walling, Walter C.: Aerodynamic Study of a Wing-Fuselage Combination Employing a Wing Swept Back 63°.- Investigation of a Large-Scale Model at Low Speed. NACA RM A8D02, 1949.

3. Cook, Woodrow L., Griffin, Roy N. Jr., and McCormack, Gerald M.: The Use of Area Suction for the Purpose of Delaying Separation of Air Flow at the Leading Edge of a 63° Swept-Back Wing. NACA RM A50H09, 1950.

TABLE I

LOCATIONS OF PRESSURE ORIFICES

Orifice number	Leading-edge flap deflected 35° down	
	Upper surface (percent chord)	Lower surface (percent chord)
1	0	---
2	.01	0.29
3	.19	1.23
4	.21	1.86
5	.43	2.44
6	.98	3.53
7	1.60	4.56
8	2.58	8.46
9	4.34	10.80
10	6.20	15.35
11[1]	10.20	20.19
12	13.20	30.16
13[2]	15.40	40.14
14	20.19	50.11
15	30.16	60.09
16	40.14	70.07
17	50.12	80.05
18	60.09	90.02
19	70.07	95.01
20	80.05	97.50
21	90.02	---
22	95.01	---
23	97.50	---

[1]Orifice 11 at 0.30 b/2 located at 9.66-percent chord
[2]Orifice 13 at 0.90 b/2 located at 16.04-percent chord

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TABLE II

WING-TIP-TANK ORDINATES

Station (percent of tank length)	Ordinate (percent of tank length)
0	0
.75	1.56
1.25	1.96
2.50	2.81
5.00	3.96
7.50	4.78
10.00	5.40
15.00	6.34
20.00	7.06
25.00	7.62
30.00	7.99
35.00	8.21
40.00	8.32
45.00	8.33
50.00	8.23
55.00	7.96
60.00	7.56
65.00	7.00
70.00	6.38
75.00	5.61
80.00	4.68
85.00	3.63
90.00	2.54
95.00	1.31
100.00	0
Nose radius: 2.02	

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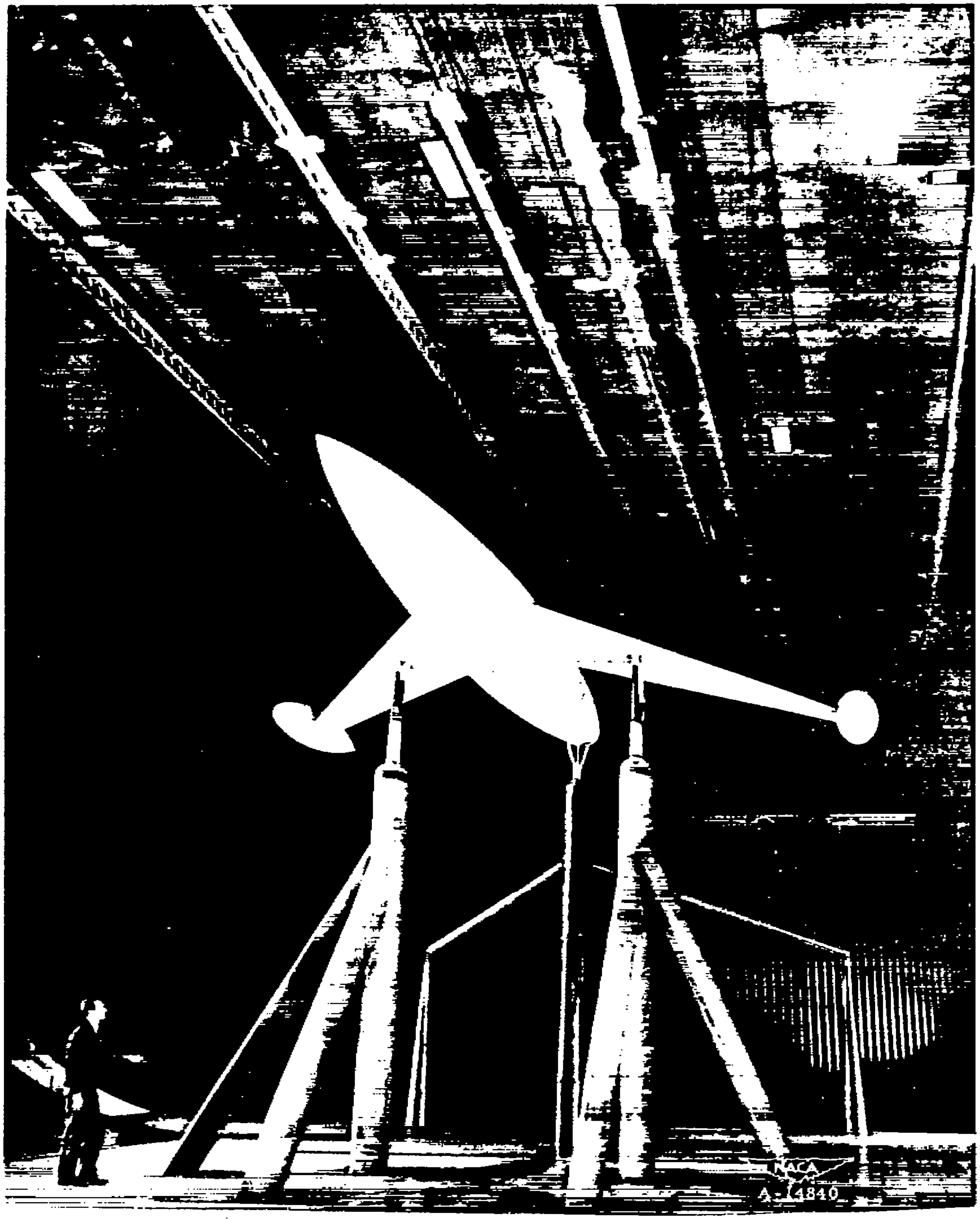


Figure 1.– The 63° swept-back wing-fuselage combination in the Ames 40- by 80-foot wind tunnel.

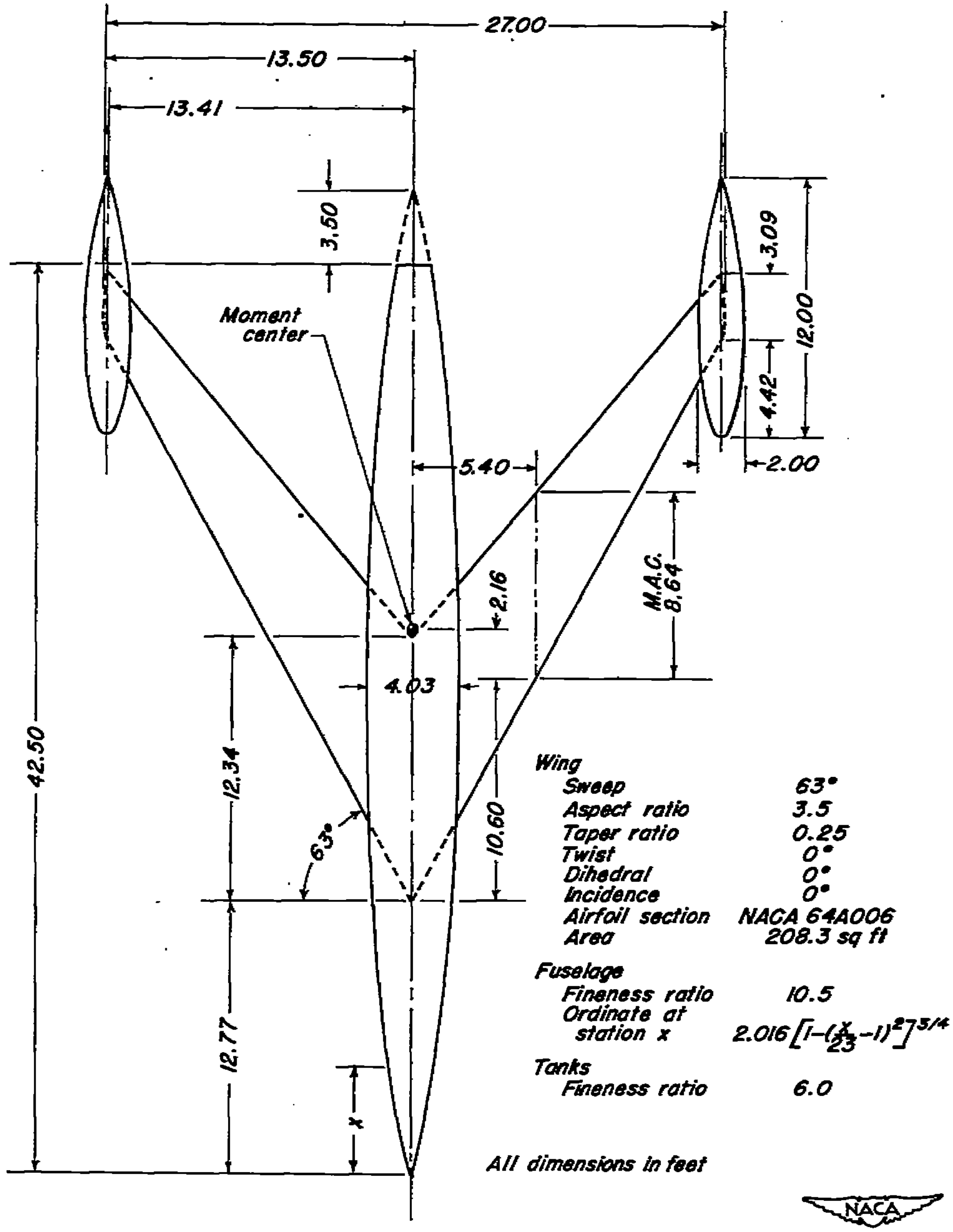
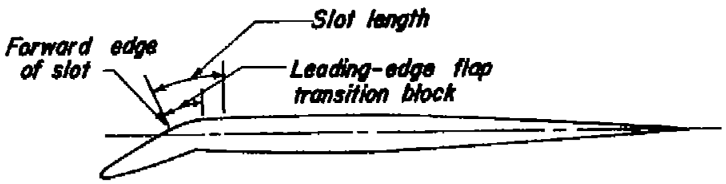


Figure 2.– Geometric characteristics of the 63° swept-back wing-fuselage combination.

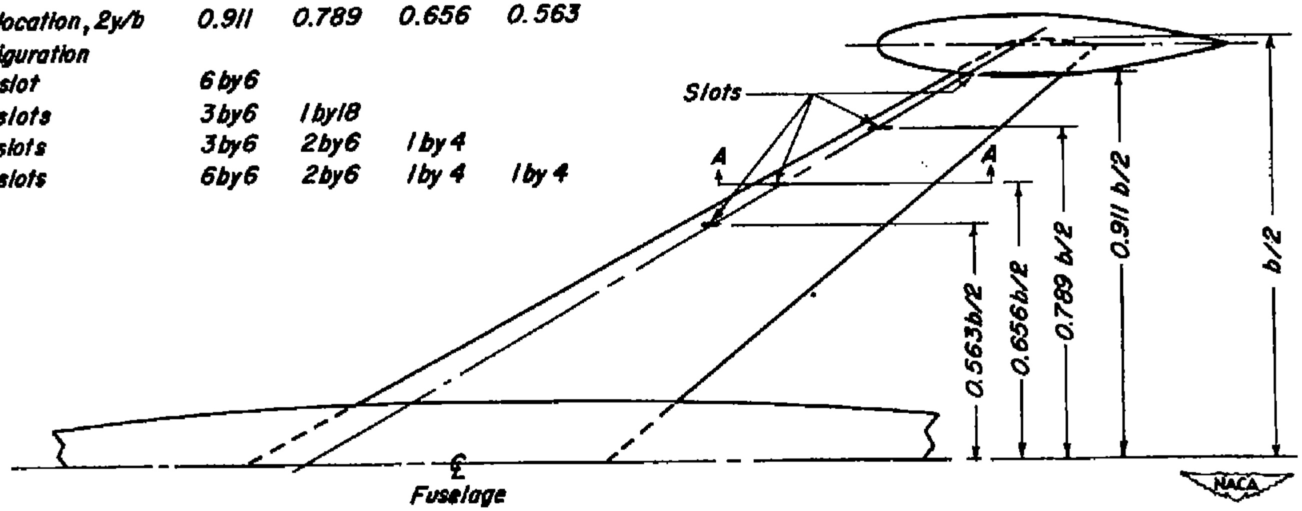
[redacted]



Section A—A

Table of slot dimensions, inches

Slot location, 2y/b	0.911	0.789	0.656	0.563
Configuration				
1 slot	6 by 6			
2 slots	3 by 6	1 by 18		
3 slots	3 by 6	2 by 6	1 by 4	
4 slots	6 by 6	2 by 6	1 by 4	1 by 4



[redacted]

Figure 3.— Slot arrangements used on the 63° swept-back wing-fuselage combination.

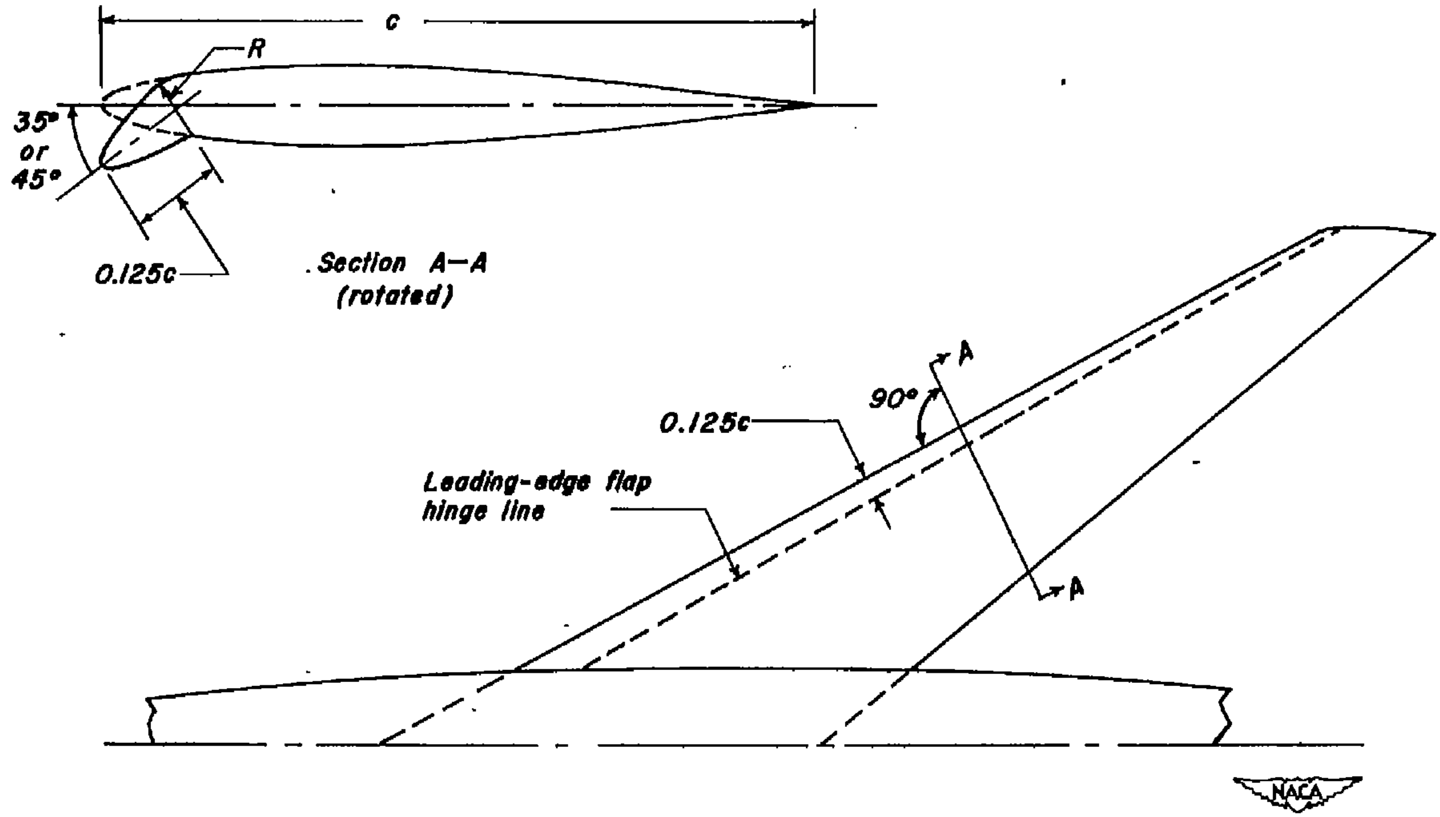


Figure 4.—Leading-edge flap used on the 63° swept-back wing-fuselage combination.

[redacted]

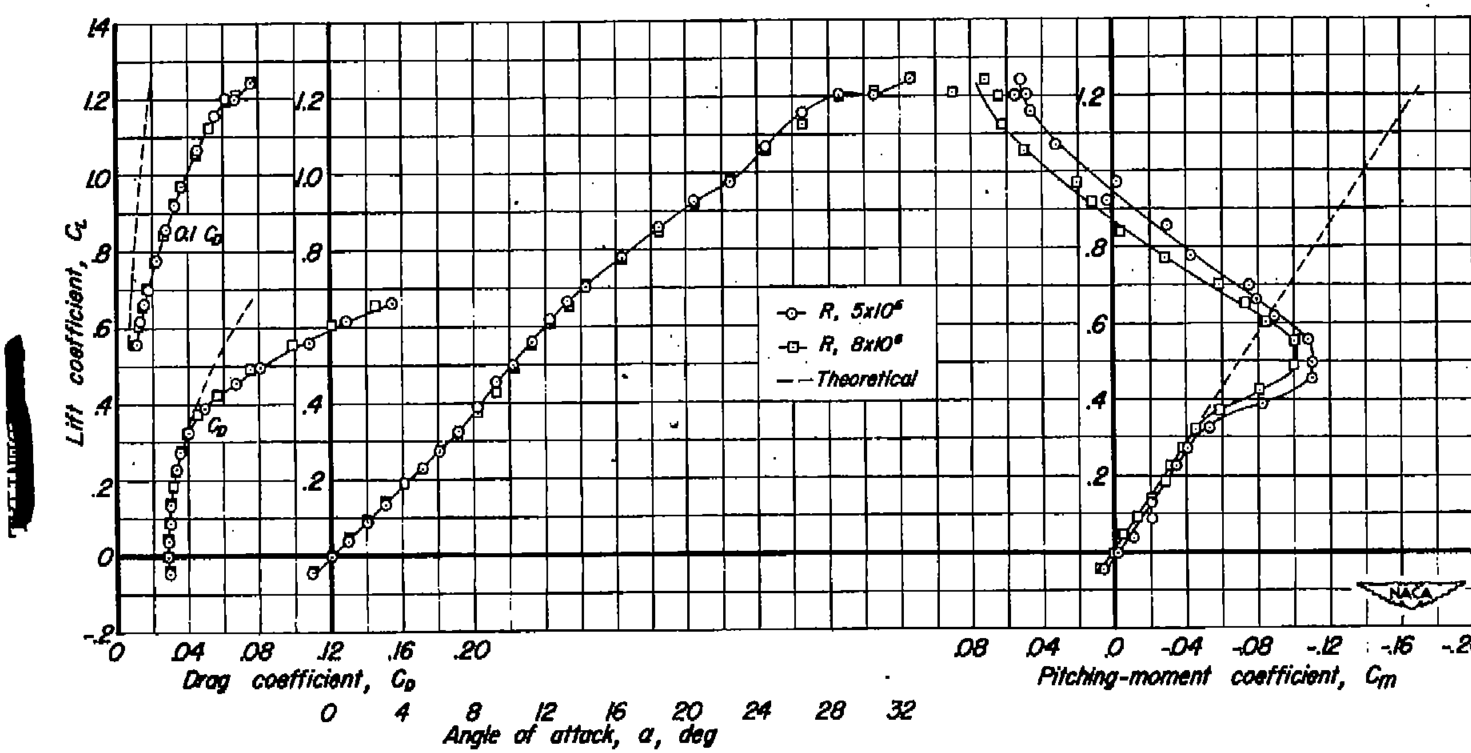
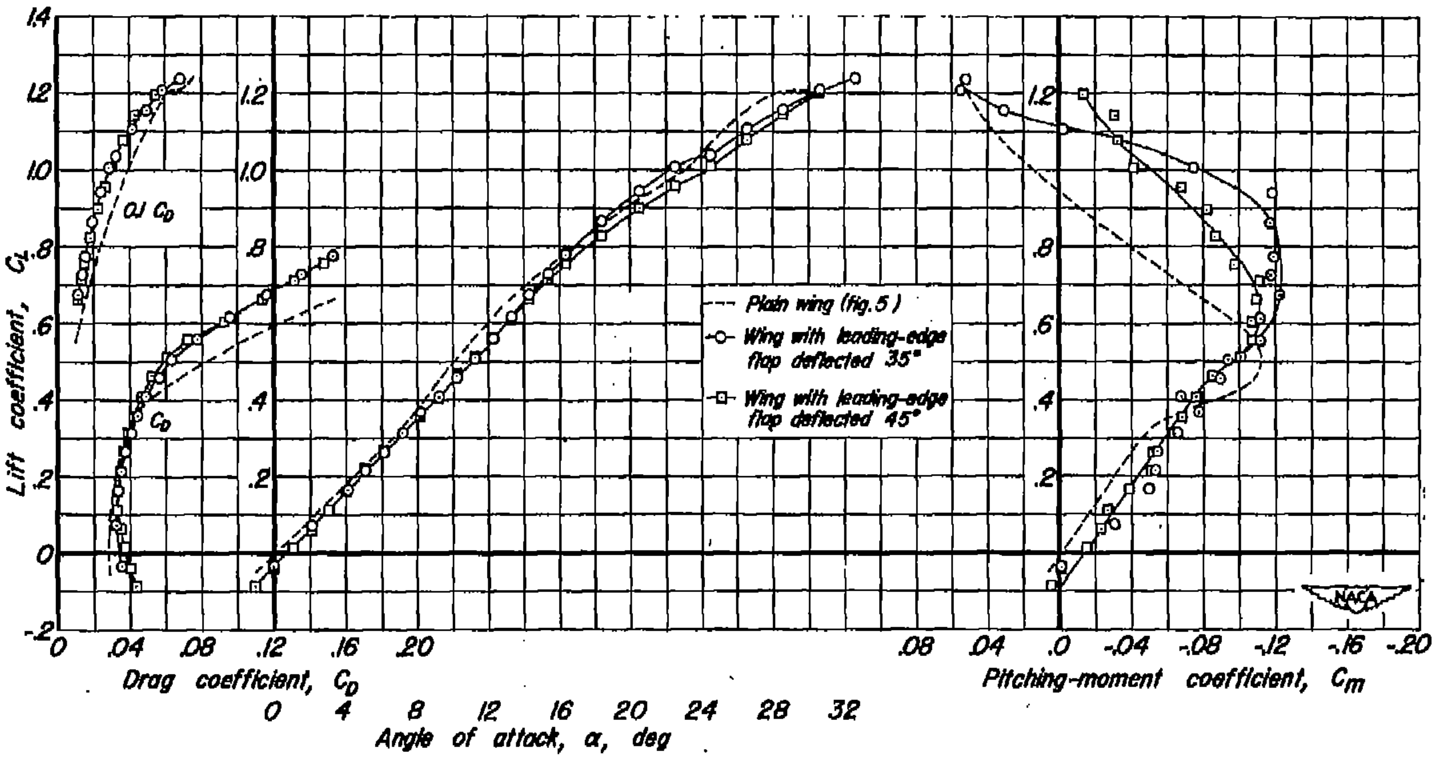


Figure 5.-The longitudinal characteristics of the 63° swept-back wing-fuselage combination.

[redacted]

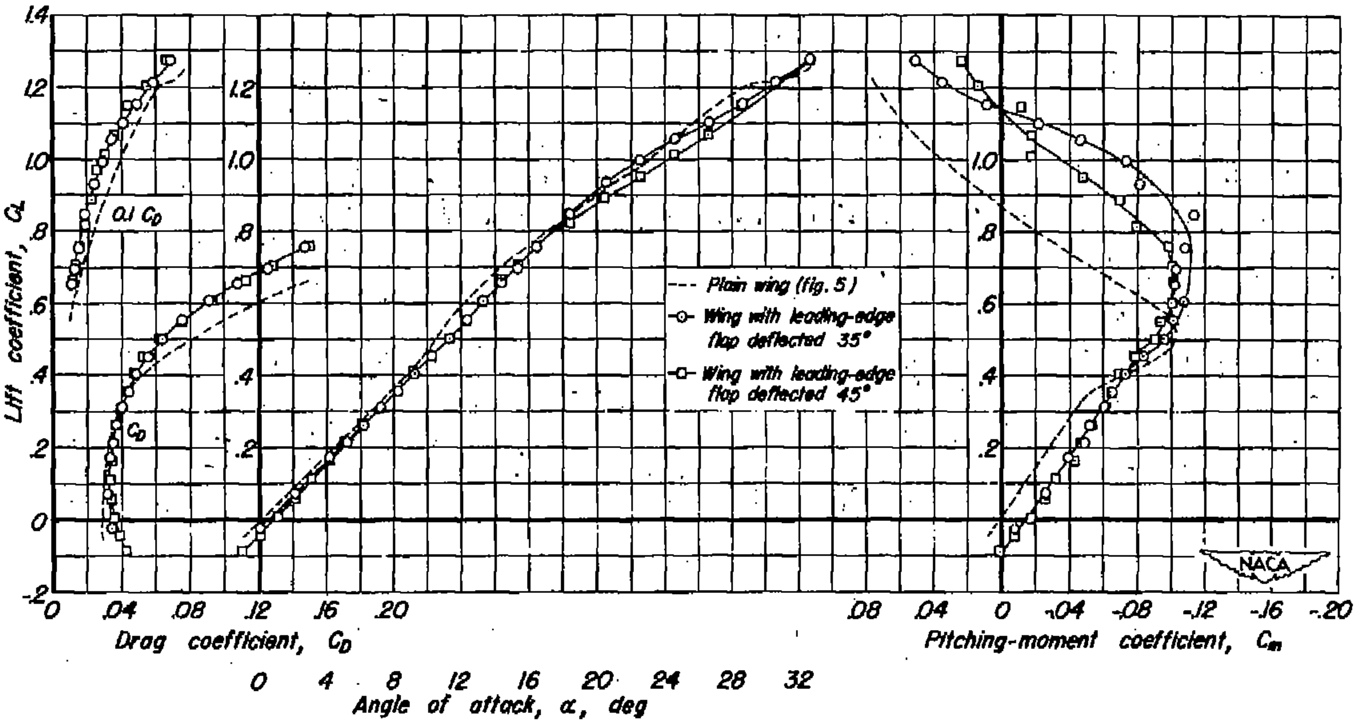
[redacted]



(a) R, 5x10⁶.

Figure 6.-The effects of full-span leading-edge flaps on the longitudinal characteristics of the 63° swept-back wing-fuselage combination at various Reynolds numbers.

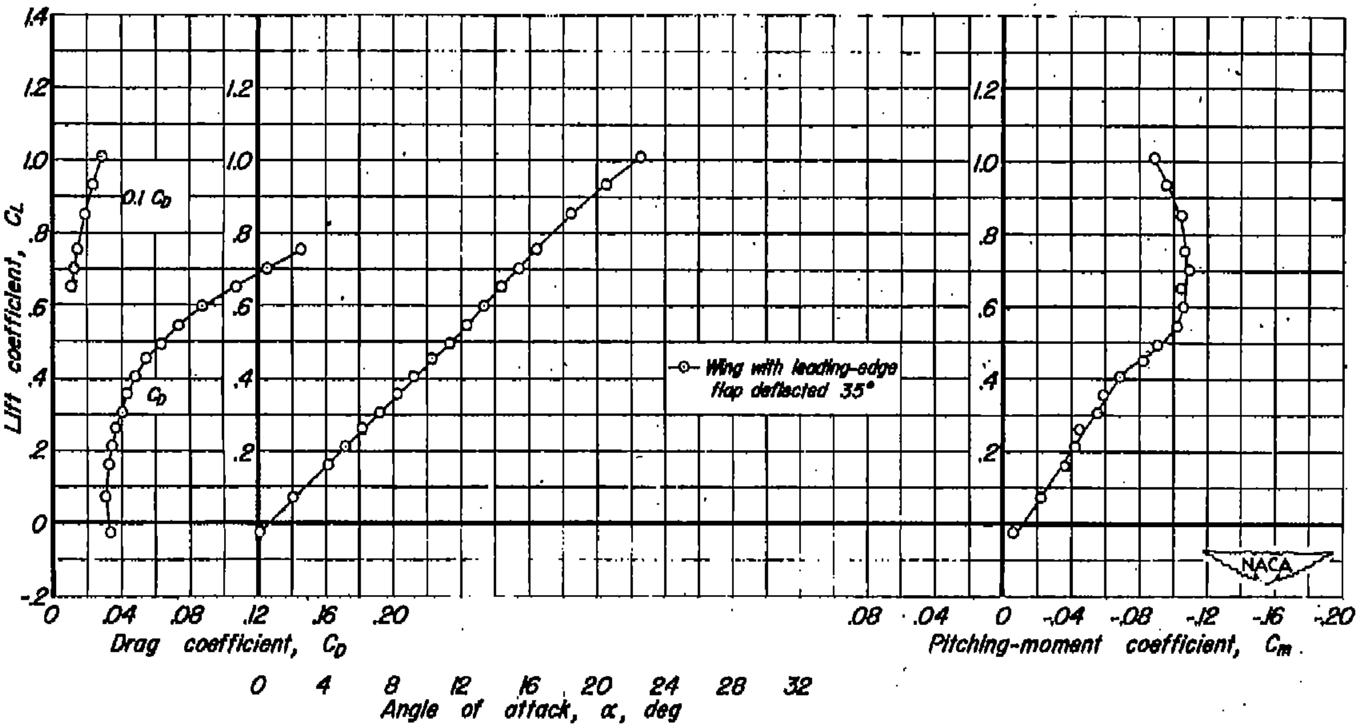
[redacted]



(b) R, 8x10[6].

Figure 6.-Continued.

[redacted]



(c) R, 10×10^6.

Figure 6.- Concluded.

[redacted]

[redacted]

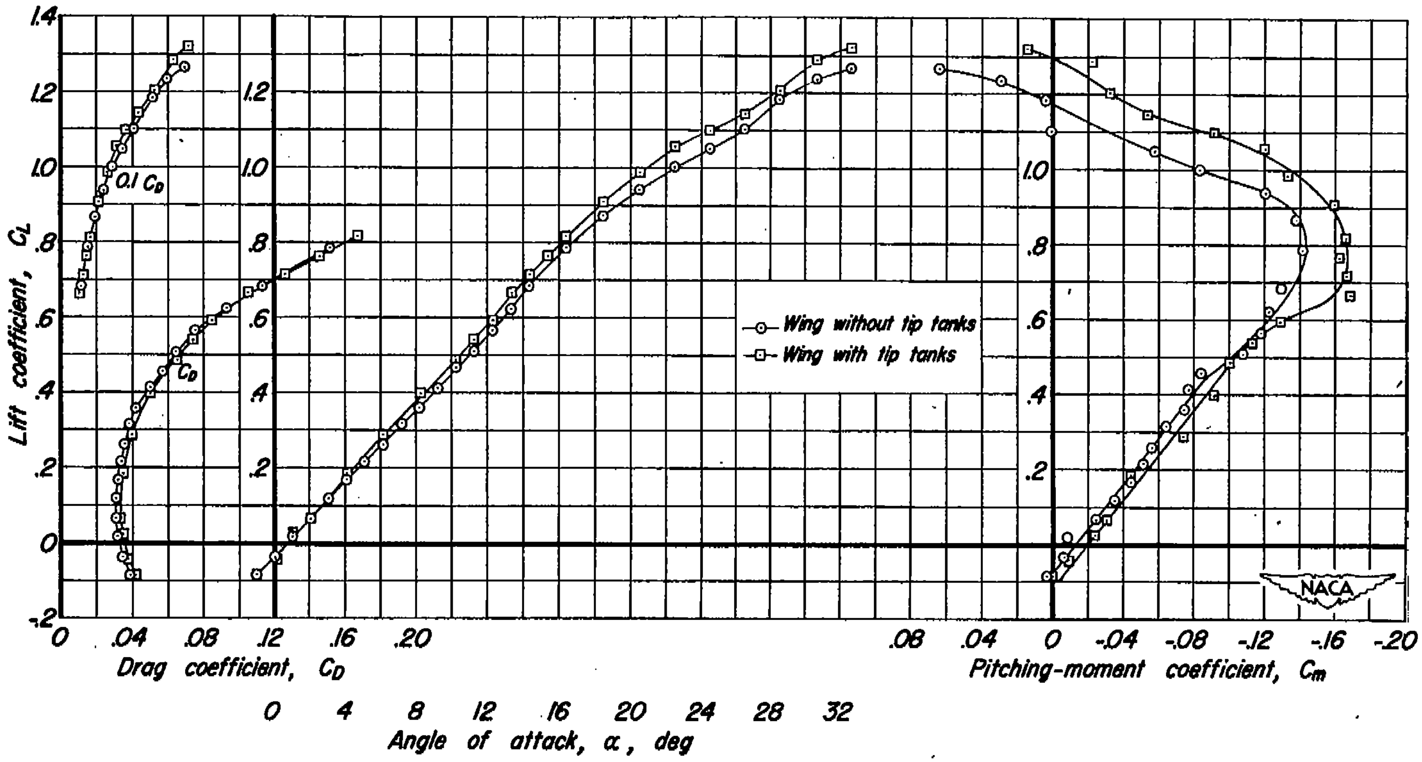


Figure 7.-The effects of tip tanks on the longitudinal characteristics of the 63° swept-back wing-fuselage combination. Full-span leading-edge flap deflected 35°. R, 5x10⁶.

[redacted]

[redacted]

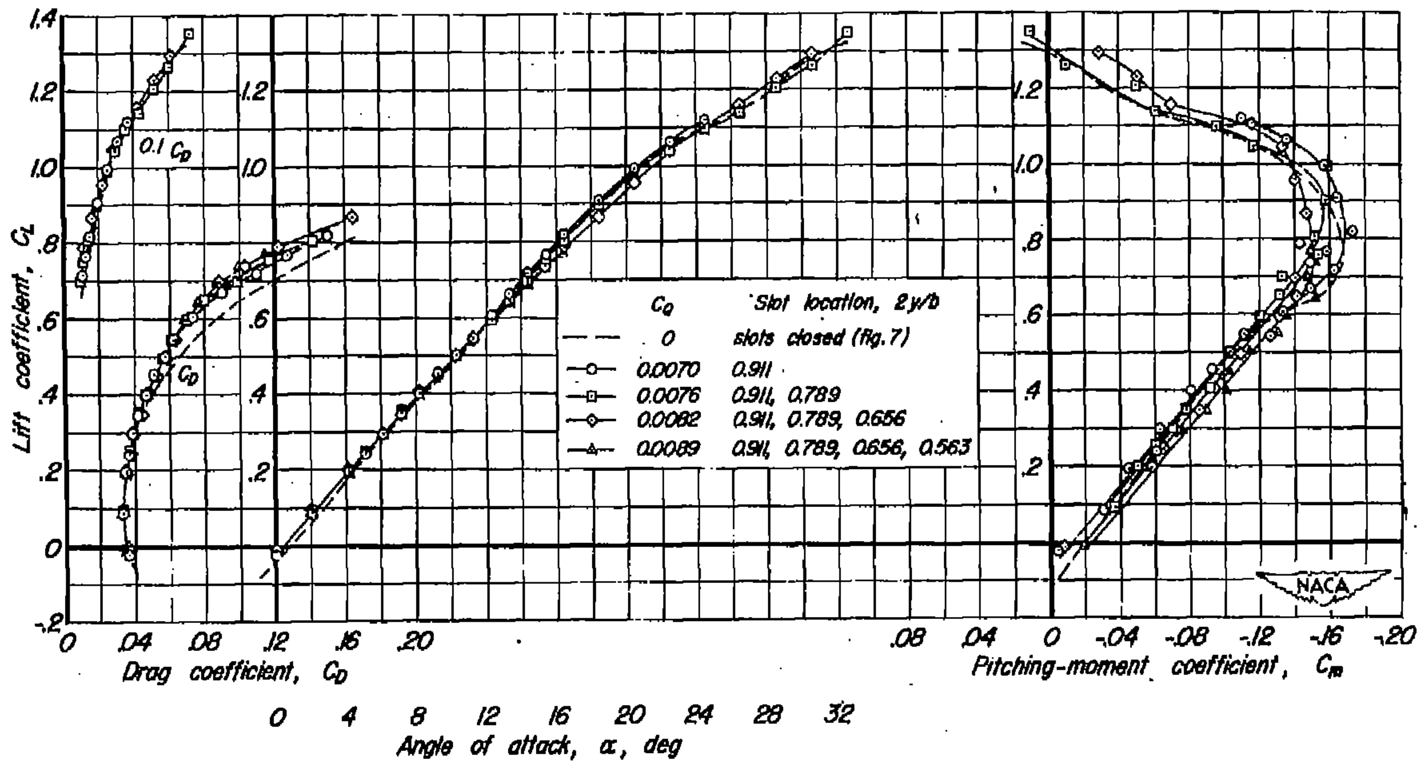


Figure 8.-The effects of suction through various slots on the longitudinal characteristics of the 63° swept-back wing-fuselage combination. Full-span leading-edge flaps deflected 35°. Tip tanks attached. R, 5x10⁶.

[redacted]

[redacted]

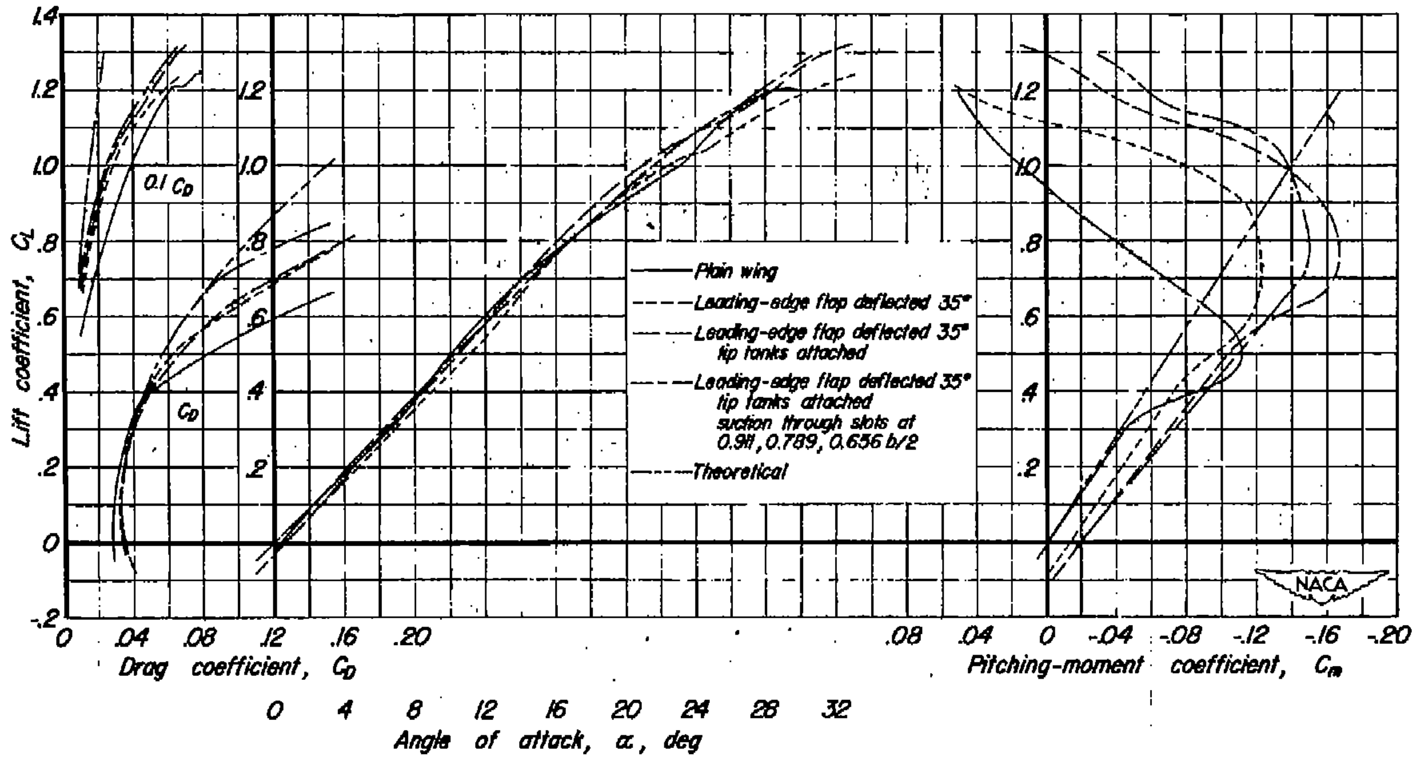


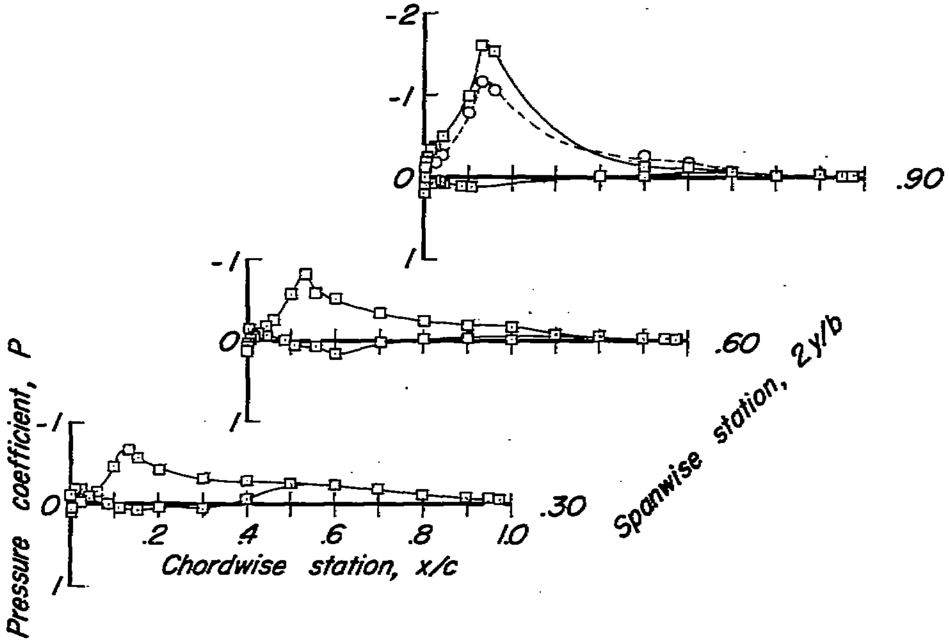
Figure 9.- Summary of the effects of the various modifications on the longitudinal characteristics of the 63° swept-back wing-fuselage combination. R, 5x10⁶.

[redacted]

--o-- *Slots closed*

—□— *Suction applied*

Note: Data obtained with slots closed not shown if essentially the same as data obtained with suction applied.

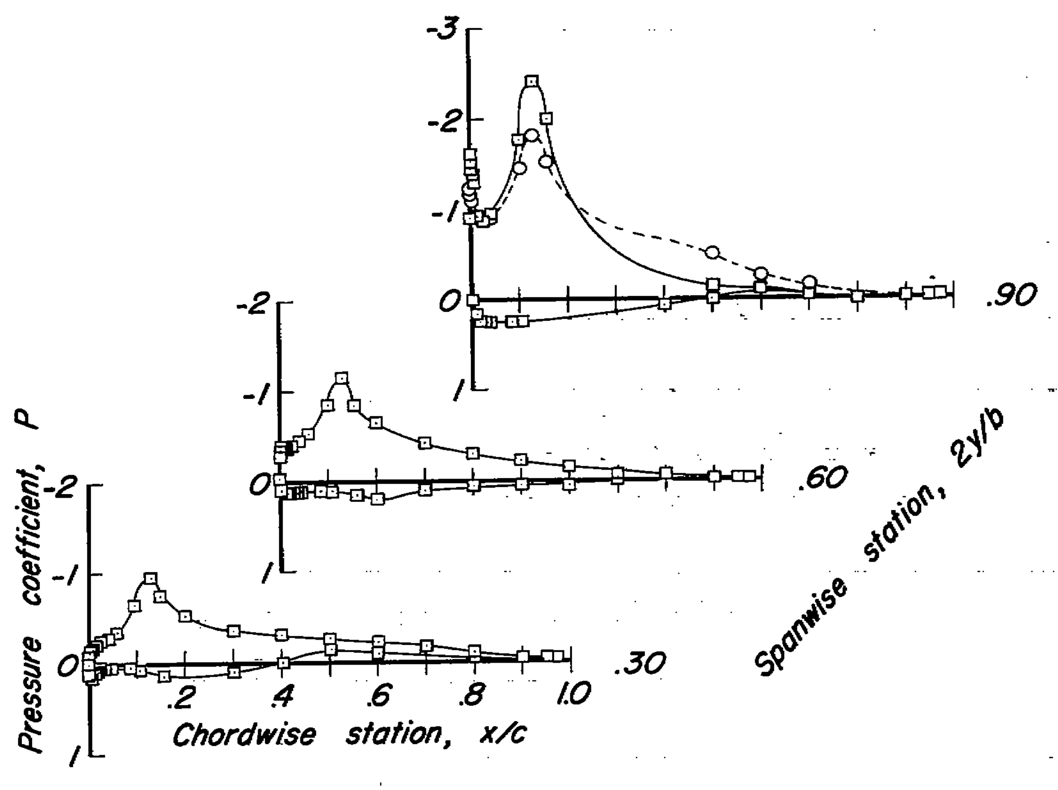


(a) $\alpha = 4.1°$.

Figure 10.- Chordwise pressure distributions for the 63° swept-back wing-fuselage combination with and without suction. Full-span leading-edge flaps deflected 35°; tip tanks attached; suction through slots at 0.656, 0.789, and 0.911 semispan. R, 5×10^6.

--○-- *Slots closed*
—□— *Suction applied*

Note: Data obtained with slots closed not shown if essentially the same as data obtained with suction applied.



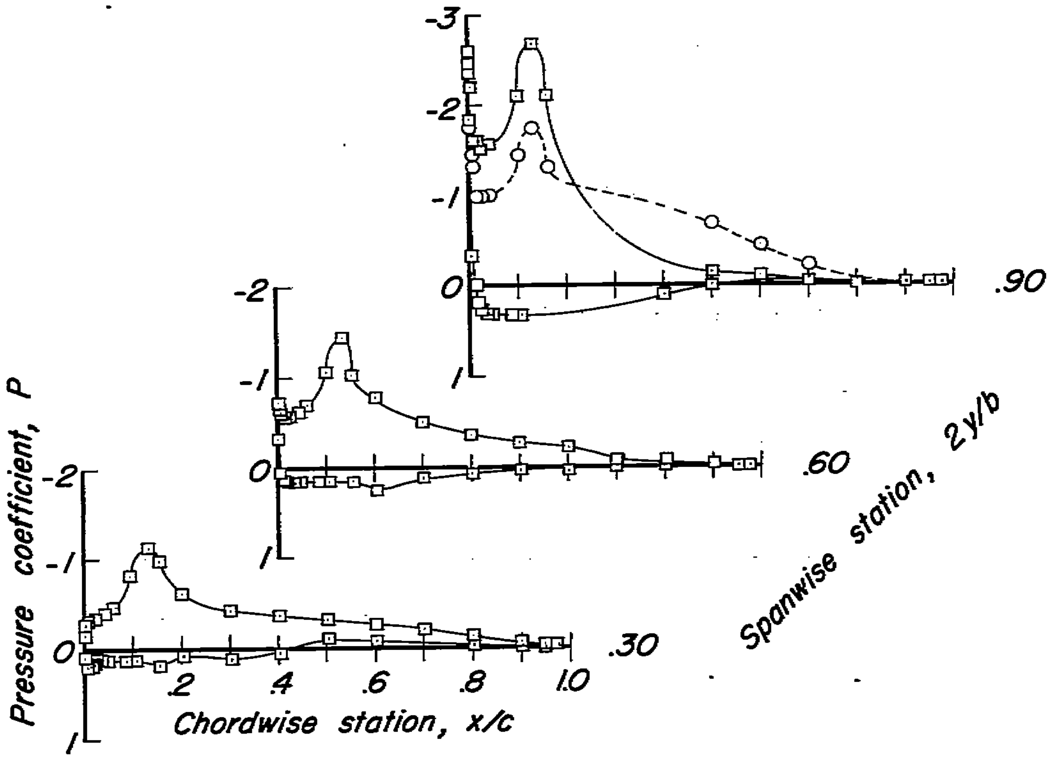
(b) $\alpha = 7.2^{\circ}$

Figure 10.- Continued.

--○-- *Slots closed*

—□— *Suction applied*

Note: Data obtained with slots closed not shown if essentially the same as data obtained with suction applied.



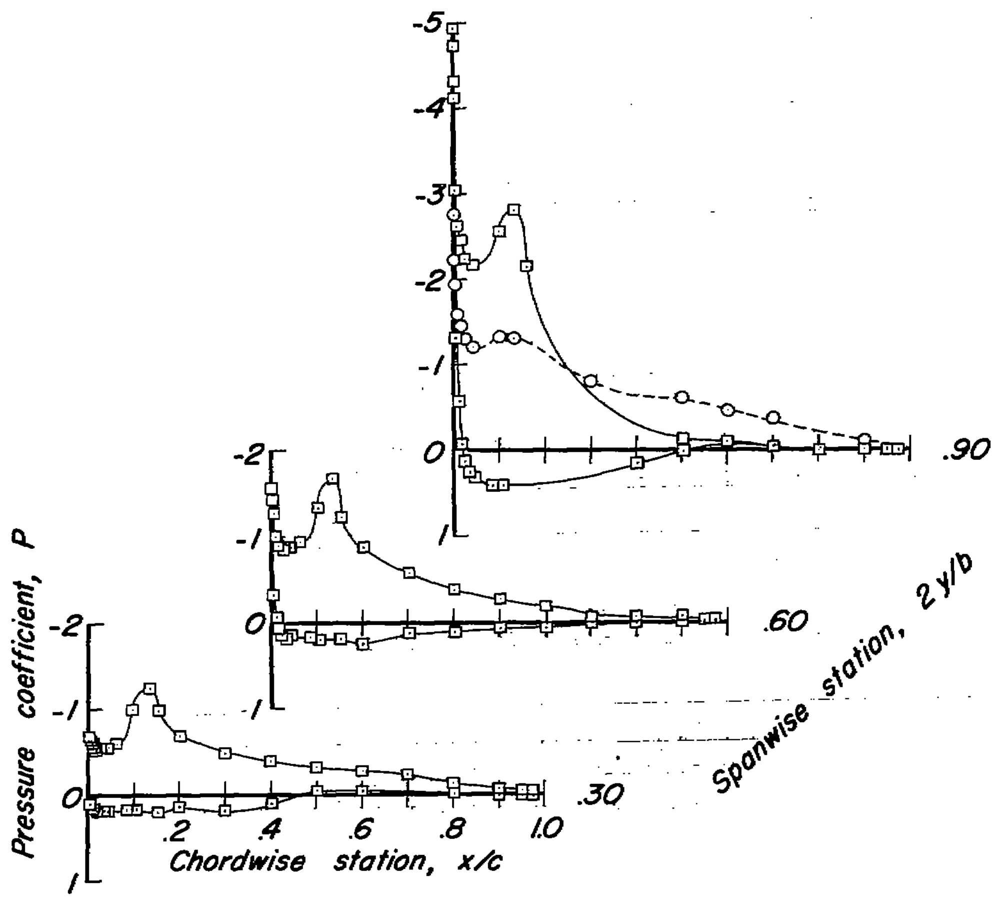
(c) $\alpha = 8.2°$.

Figure 10.- Continued.

--o-- *Slots closed*

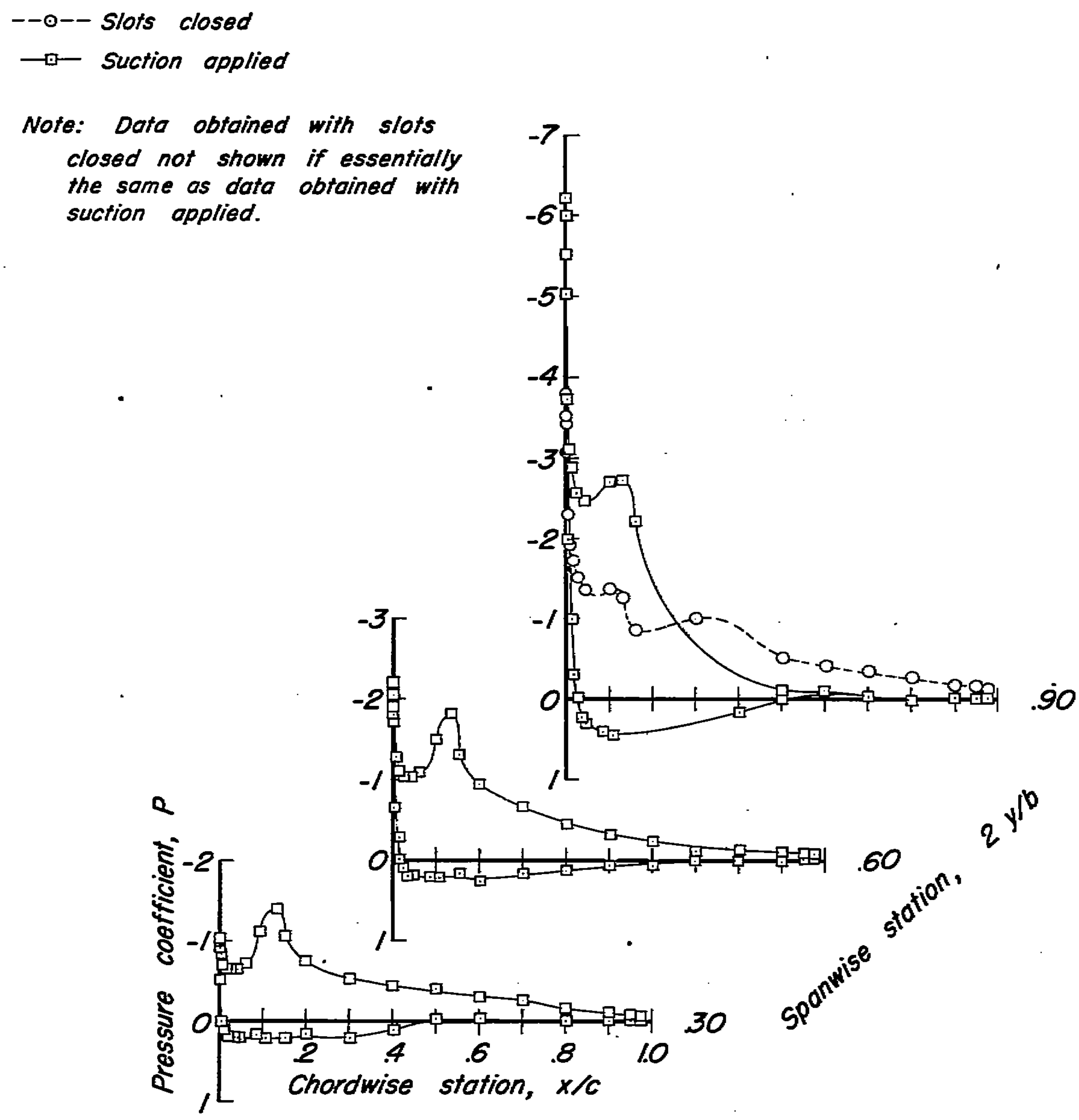
—□— *Suction applied*

Note: Data obtained with slots closed not shown if essentially the same as data obtained with suction applied.



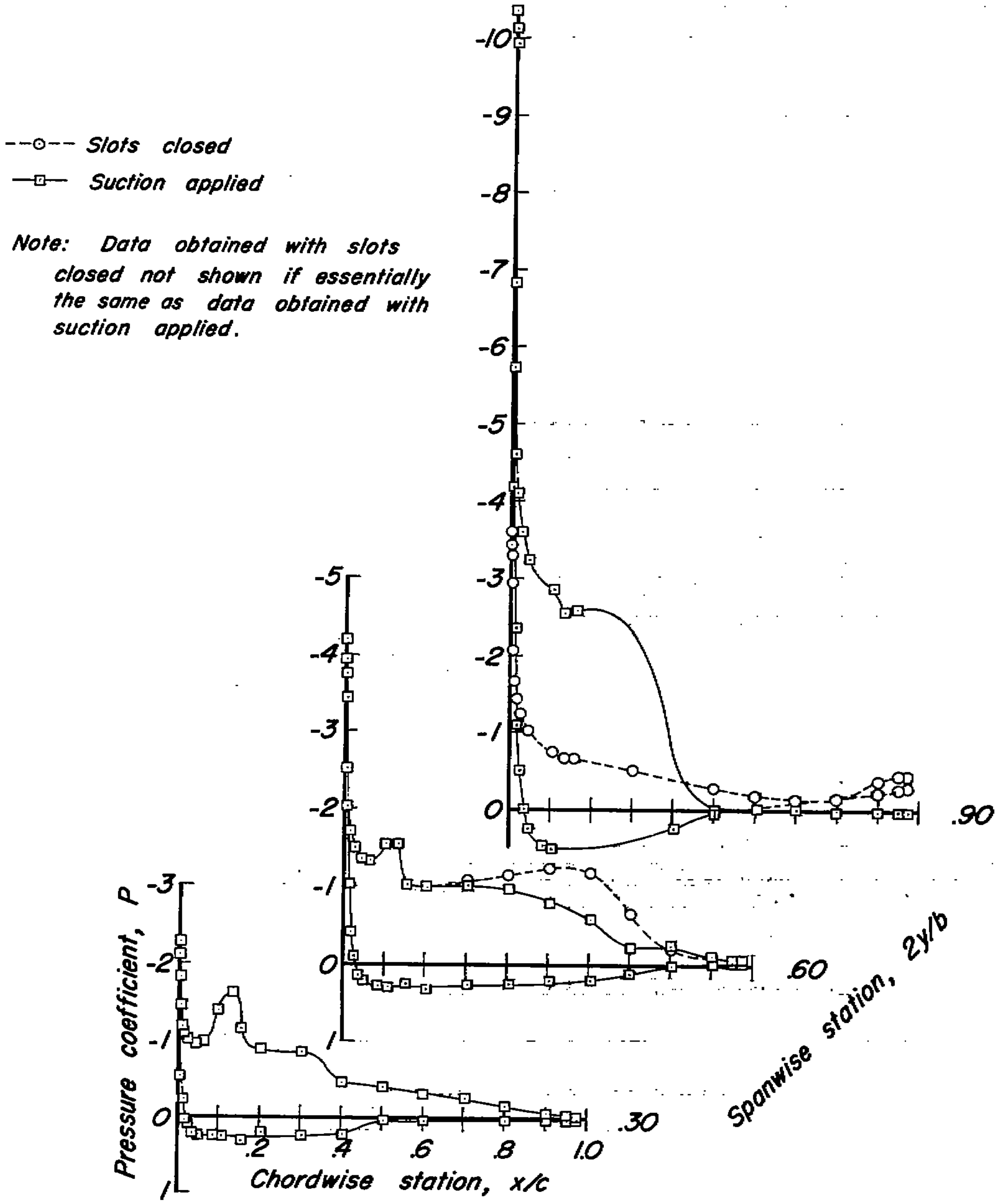
(d) α = 10.3°.

Figure 10.-Continued.



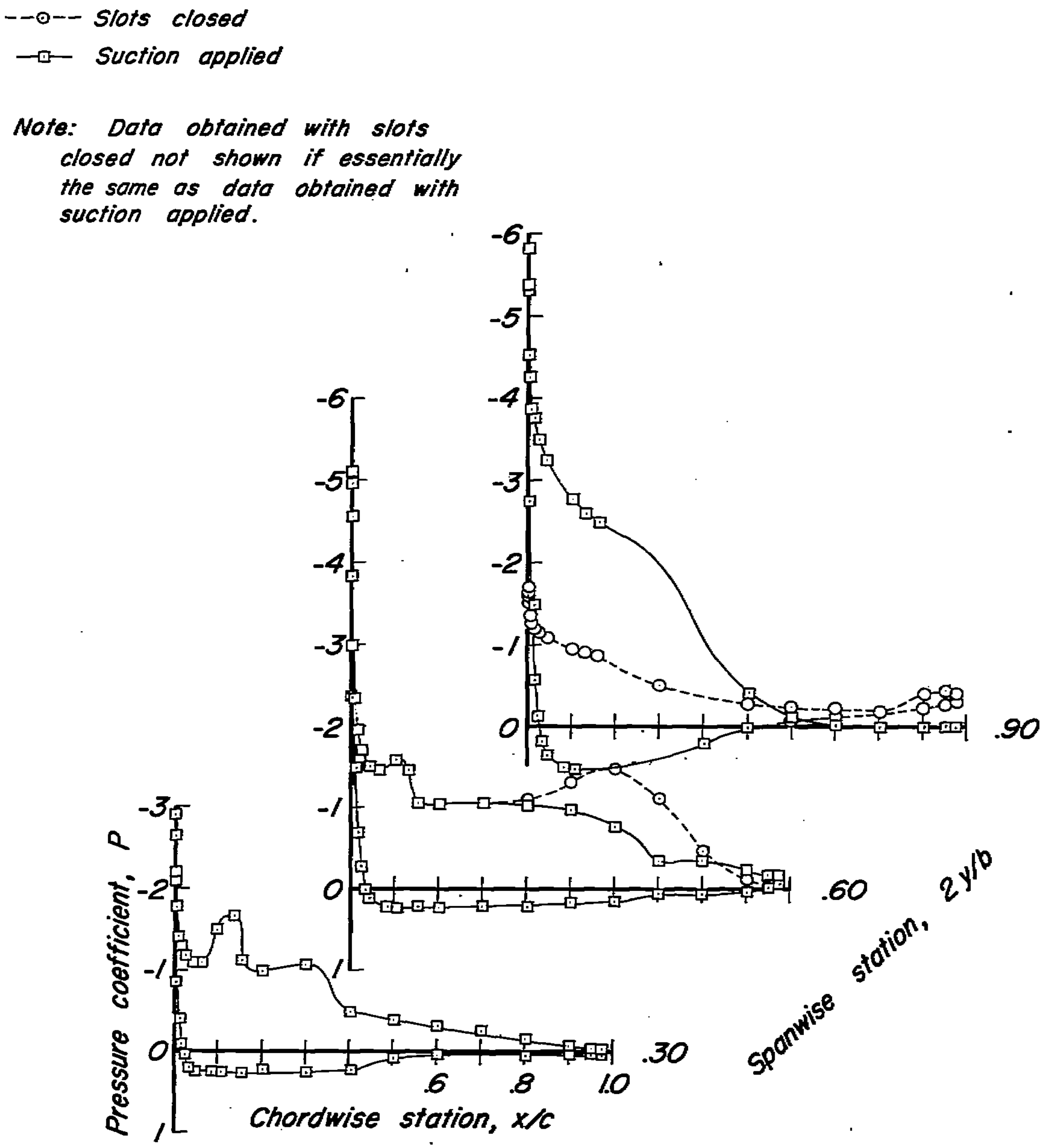
(e) $\alpha = 11.3°$.

Figure 10.-Continued.



(f) $\alpha = 14.4°$.

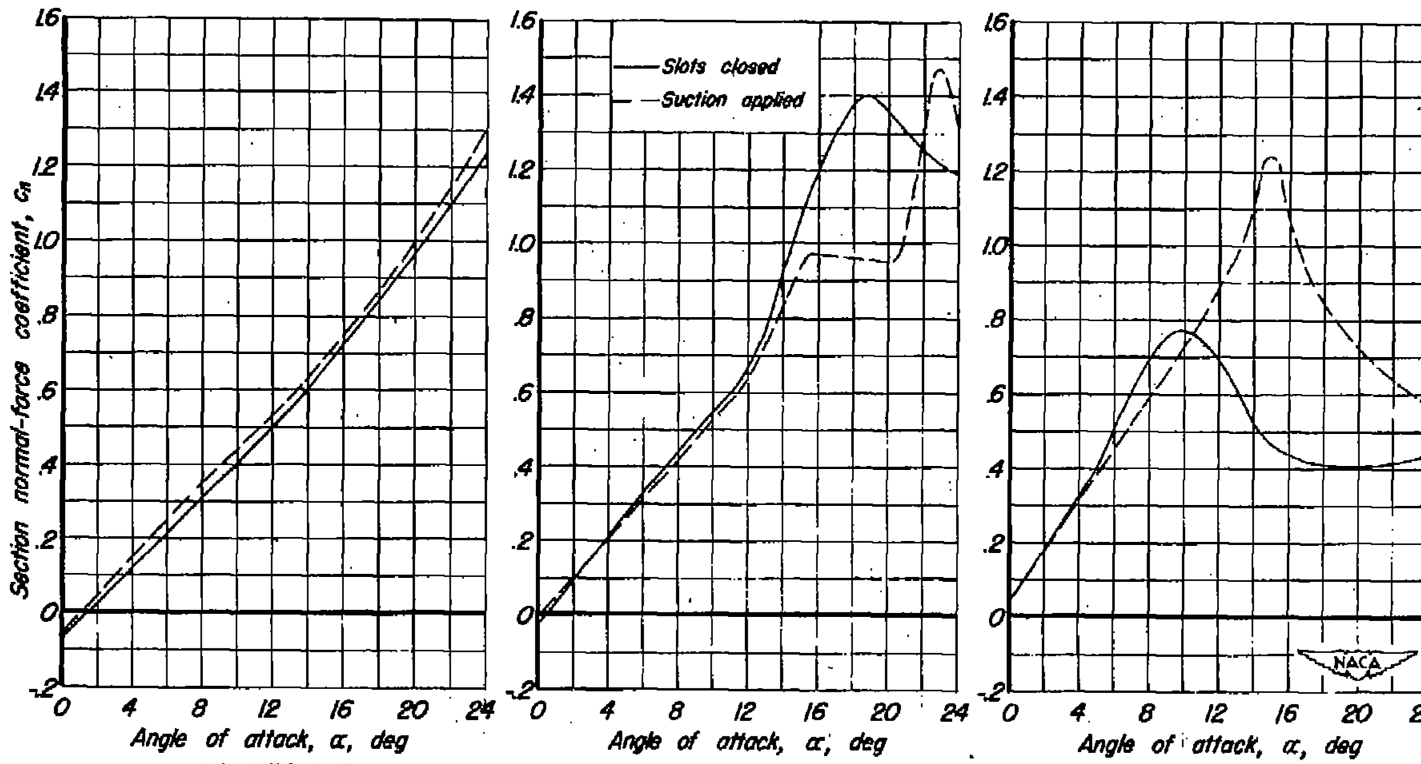
Figure 10.-Continued.



(g) $\alpha = 15.4°$.

Figure 10.-Concluded.

[redacted]



(a) 0.30 b/2.

(b) 0.60 b/2.

(c) 0.90 b/2.

Figure 11.-Normal-force curves for various sections of the 63° swept-back wing-fuselage combination with and without suction. Full-span leading-edge flaps deflected 35°; tip tanks attached; suction through slots at 0.656, 0.789, and 0.911 semispan. R, 5×10^6.

[redacted]